

# Southeast Regional Carbon Sequestration Partnership

## **Presented to:**

Regional Carbon Sequestration  
Partnerships  
Annual Review Meeting  
Development Phase Field Tests

*Pittsburgh, PA  
October 5, 2010*

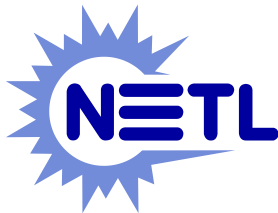
## **Presented by:**

*Gerald R. Hill, Ph.D.  
Senior Technical Advisor  
Southern States Energy Board*



# Acknowledgements

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- This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory.
- Cost share and research support provided by SECARB/SSEB Carbon Management Partners

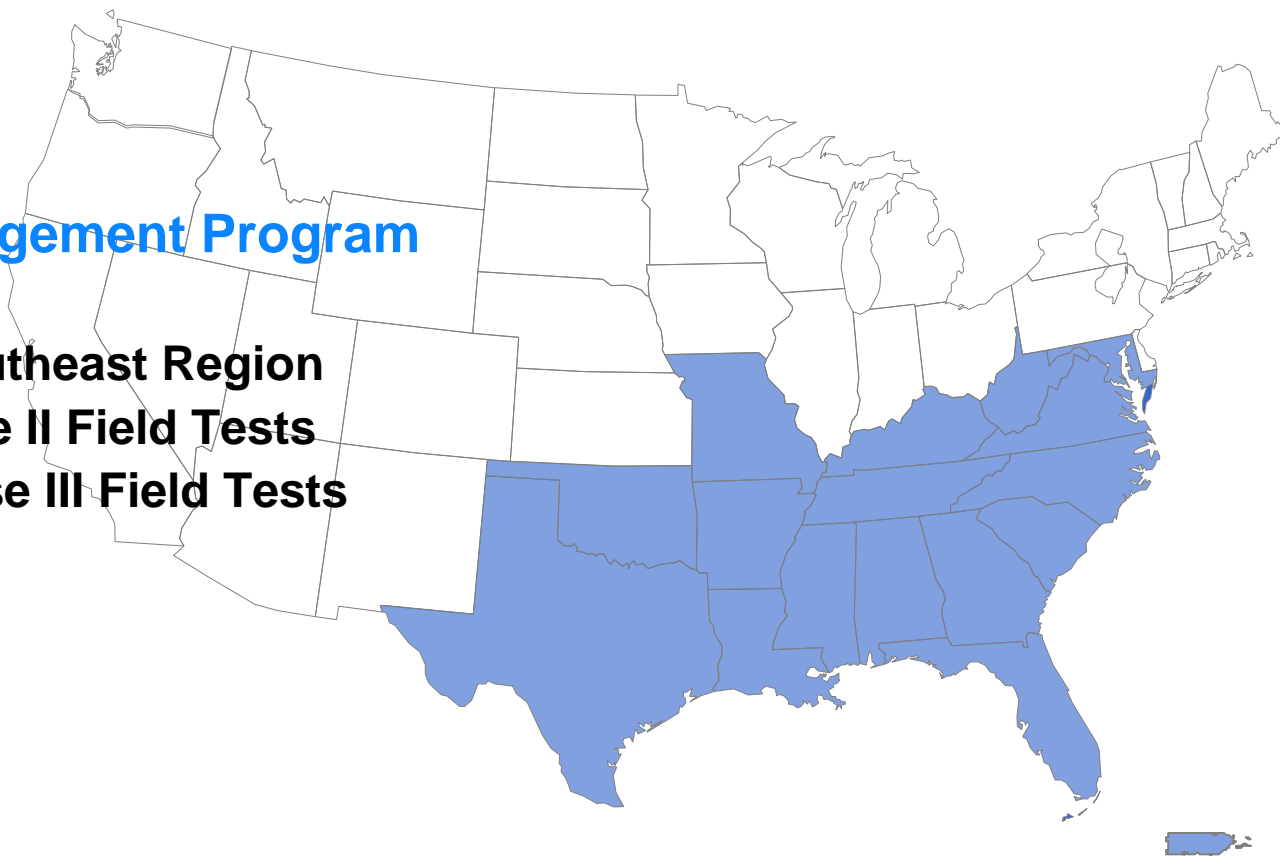


*Through innovations in energy and environmental policies, programs and technologies, the Southern States Energy Board enhances economic development and the quality of life in the South.*

*- SSEB Mission Statement*

## **SSEB Carbon Management Program**

- ★ **Established 2003**
- ★ **Characterizing Southeast Region**
- ★ **Completed 4 Phase II Field Tests**
- ★ **Conducting 2 Phase III Field Tests**



# SECARB Participants: Diverse and Numerous (100+)

Advanced Resources International  
Alabama Power Company  
Alpha Natural Resources  
American Coalition for Clean Coal  
Electricity  
American Electric Power  
Amvest Gas Resources, Inc.  
AMVEST Oil and Gas  
ARCADIS US  
Arch Coal  
Augusta Systems, Inc.  
Baker Hughes, Inc.  
Blue Source  
Bright Energy, LLC  
BP America, Inc.  
BP Alternative Energy  
CDX Gas, LLC  
Clemson University  
CNX Gas  
CONSOL, Inc.  
CSX Transportation  
Dart Oil & Gas Corporation  
Dart Energy Corporation  
Denbury Resources, Inc.  
DNV  
Dominion Energy  
Dominion Resources  
Duke Energy

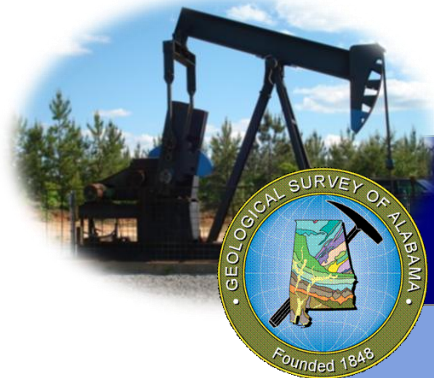
Dupont Titanium Technologies  
Eastern Coal Council  
Electric Power Research Institute (EPRI)  
Entergy Services  
Equitable Production Company  
Exxon Mobil Production Company  
F.D. Robertson  
Florida Municipal Electric Association  
Florida Power & Light Company  
Geological Survey of Alabama  
GeoMet  
Halliburton  
Hilcorp Energy Company  
Kentucky Energy & Environment-Division of  
Energy Development & Independence  
Kentucky Geological Survey  
Interstate Oil and Gas  
Compact Commission  
Marshall Miller & Associates  
Massachusetts Institute of Technology  
McJunkin Appalachian Oilfield Company  
Mississippi Power Company  
Mississippi State University (MSU)  
Natural Resources Partners  
NRG Energy  
Old Dominion Electric Cooperative  
Penn Virginia Operating Company, LLC  
Penn Virginia Resources

Petron Resources  
Piney Land Company  
Pocahontas Land Corporation  
Praxair  
Progress Energy  
RMB Earth Science Consultants, Ltd.  
Santee Cooper Power  
SCANA Energy  
Schlumberger  
Shell Exploration & Production Company  
S&ME, Inc/ EMS Services  
Smith Energy  
South Carolina Electric & Gas Company  
Southern Company  
Southern Company Services  
Southern Natural Gas & El Paso  
Exploration and Production   
Southern States Energy Board  
Teco Coal Corporation  
Tennessee Valley Authority  
Texas Bureau of Economic Geology  
-Gulf Coast Carbon Center  
U.S. Department of Energy/National  
Energy Technology Laboratory  
Virginia Tech  
VA Center for Coal and Energy Research  
West Virginia University

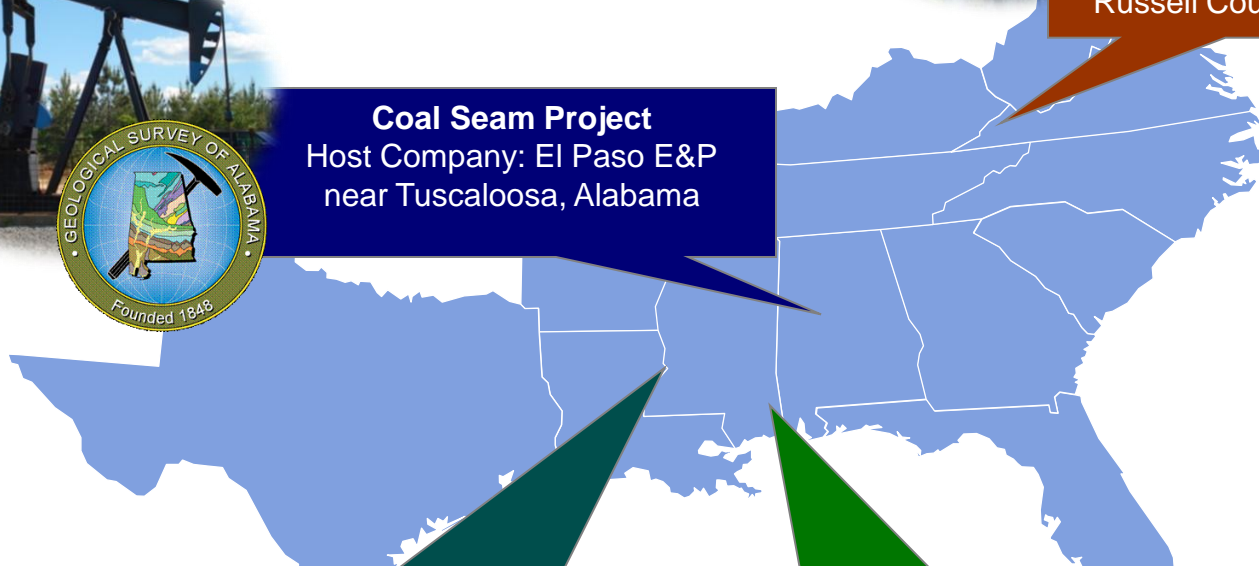
# SECARB Phase II



**Coal Seam Project**  
Host Company: CNX Gas  
Russell County, Virginia



**Coal Seam Project**  
Host Company: El Paso E&P  
near Tuscaloosa, Alabama



**Stacked Storage Project**  
Cranfield Test Site  
Host Company: Denbury Resources, Inc.  
near Natchez, Mississippi

**Mississippi Test Site**  
Mississippi Power's Plant Daniel  
Escatawpa, Mississippi





# SECARB Phase III

**SECARB Early Test was recognized by DOE for furthering CCS technology and meeting G-8 goals for deployment of 20 similar projects by 2020. The Early Test is the fifth project worldwide to reach the CO<sub>2</sub> injection volume of one million tonnes and the first in the U.S.**

- (DOE Techline, 11/05/2009)

**EPR2** | ELECTRIC POWER  
RESEARCH INSTITUTE

## Anthropogenic Test

Capture: Alabama Power Plant Barry,  
Bucks, Alabama

Transportation: Denbury Resources

Geo Storage: Denbury's Citronelle Field,  
Citronelle, Alabama

## Early Test

Denbury Resources' Cranfield Field  
Near Natchez, Mississippi



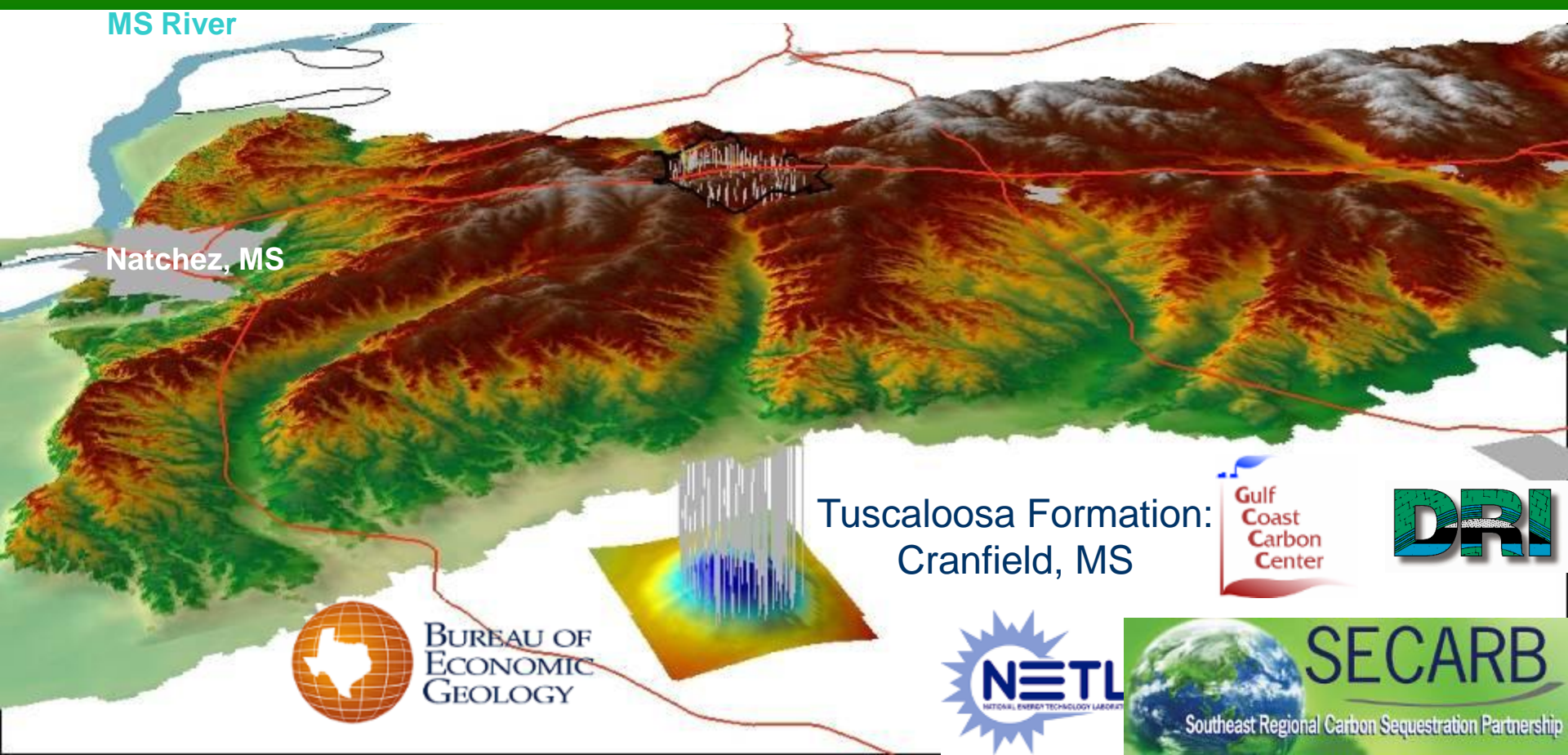
# SECARB Early Large Volume Injection Tests

Cranfield Unit operated by Denbury Resources Inc

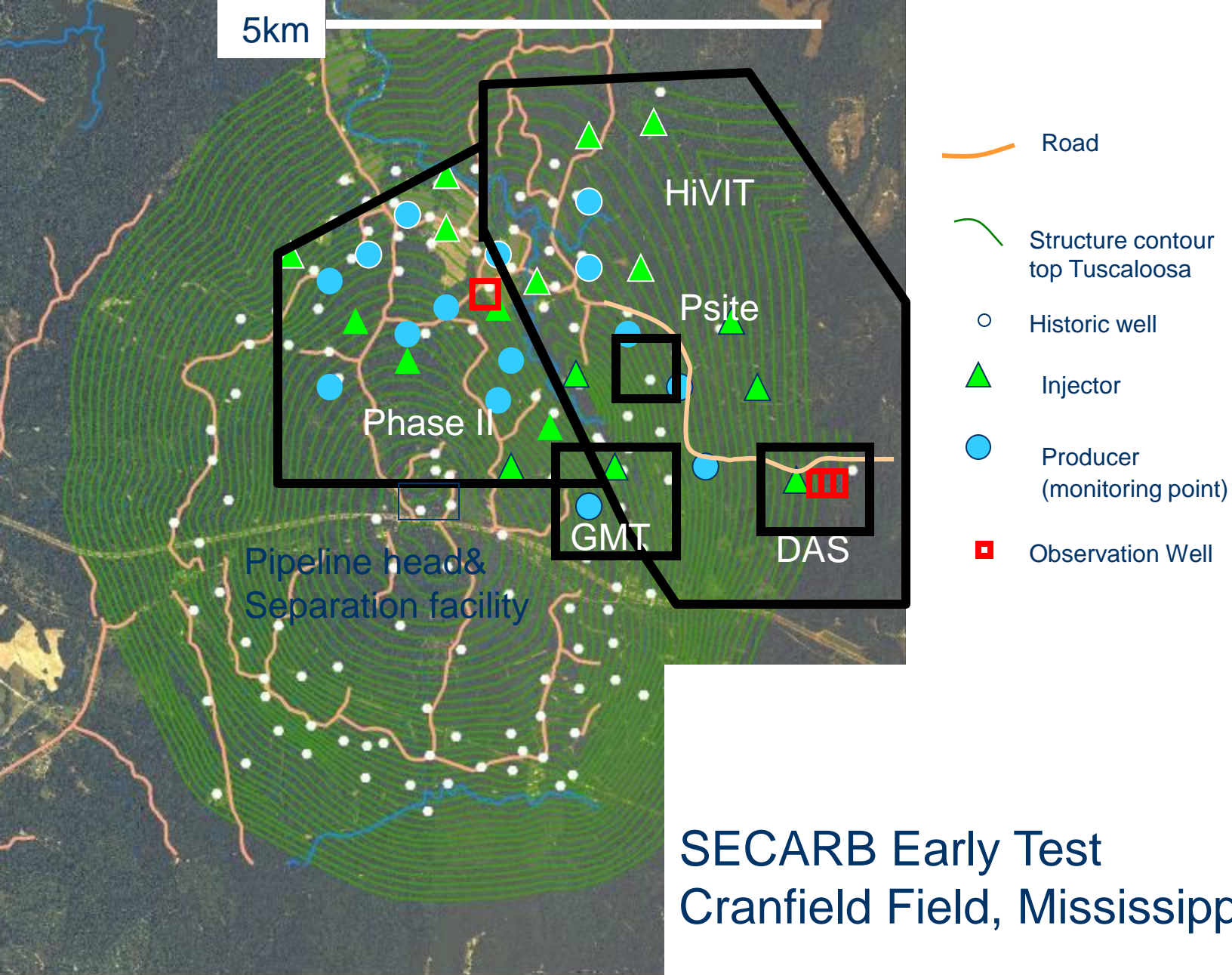
Depth >10,300 ft

Injection Zone – lower Tuscaloosa Formation

Injection rate >1 Million tonnes per year

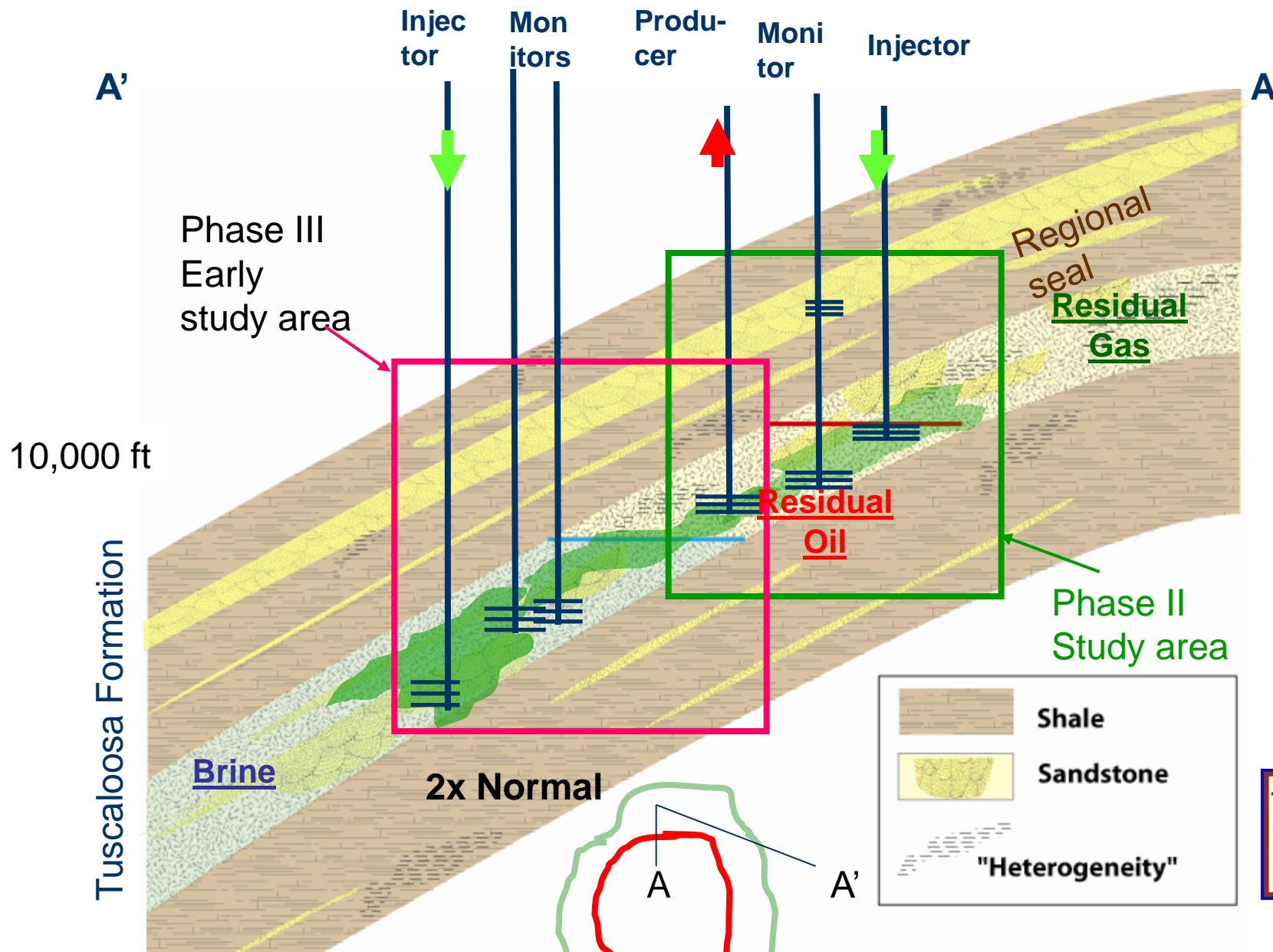








# Cranfield Geometric Overview



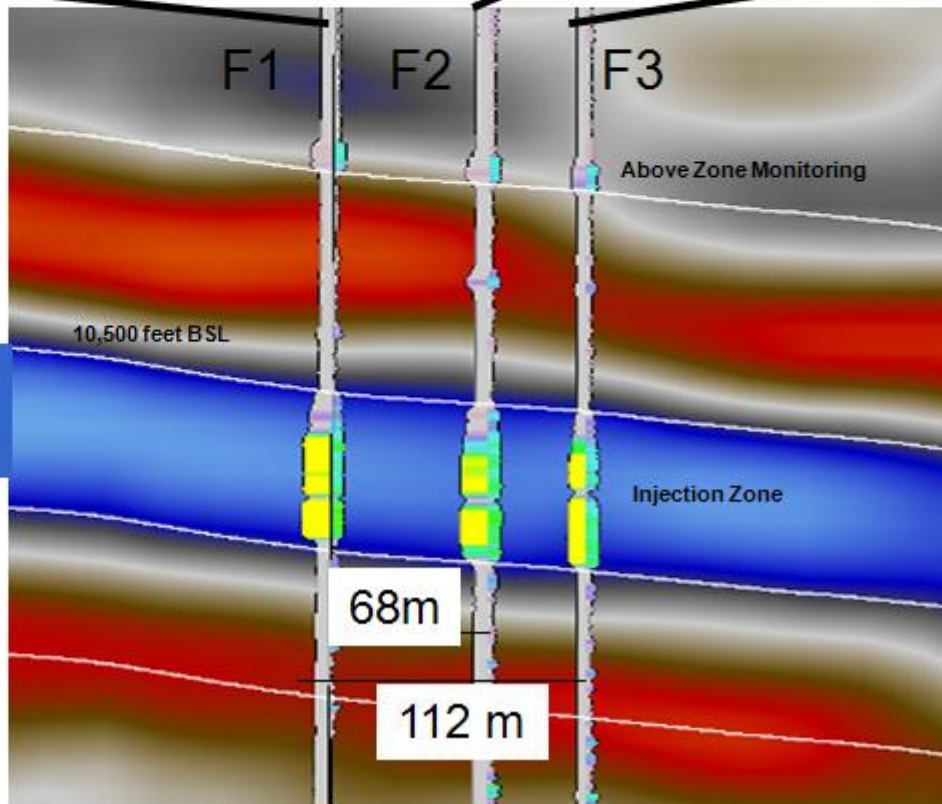
# Cranfield Early Test Monitoring: Detailed Area of Study



Closely spaced well array to examine flow in complex reservoir

Confining system

Lower Tuscaloosa injection zone

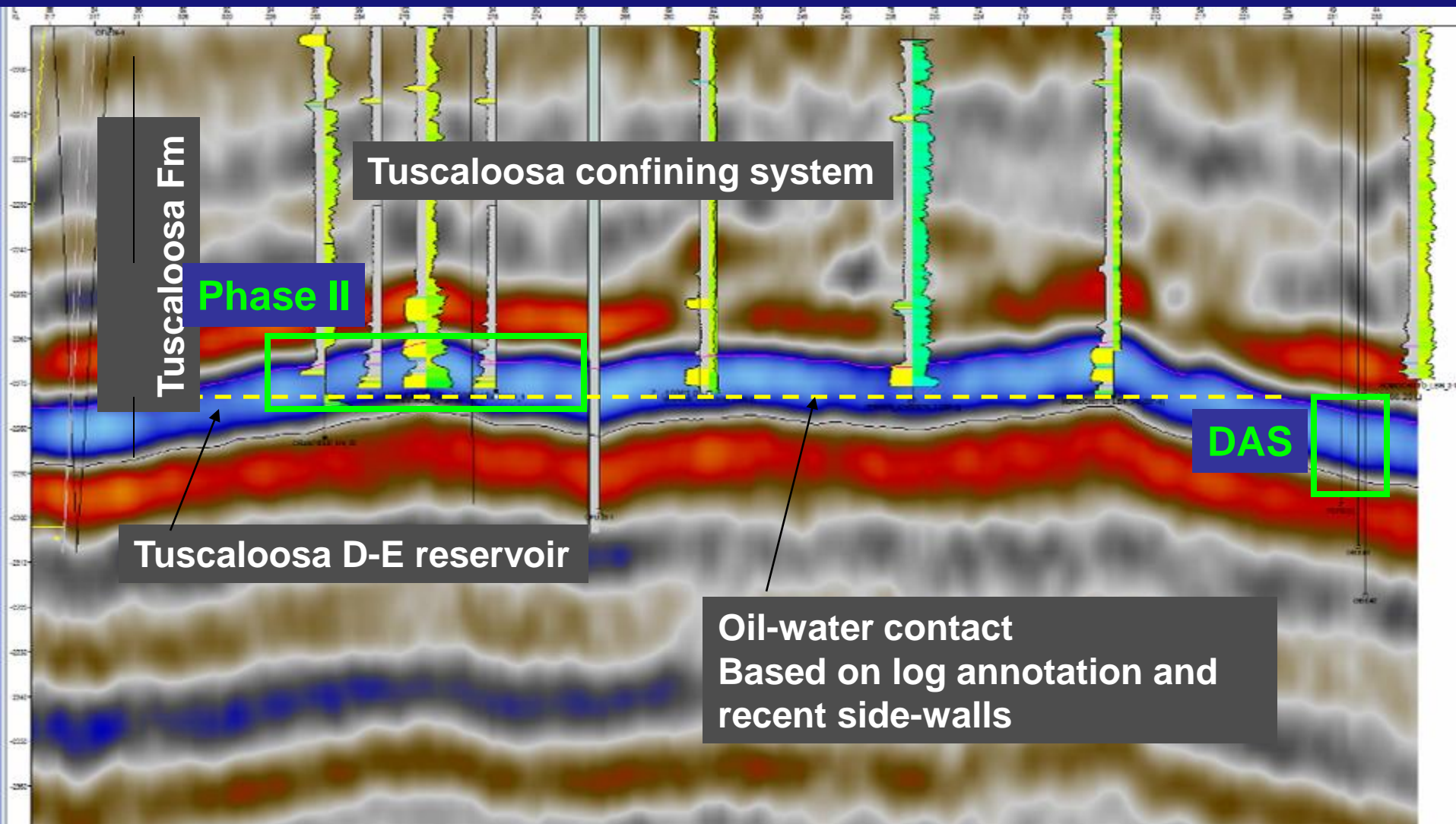




# Characterization of the Reservoir

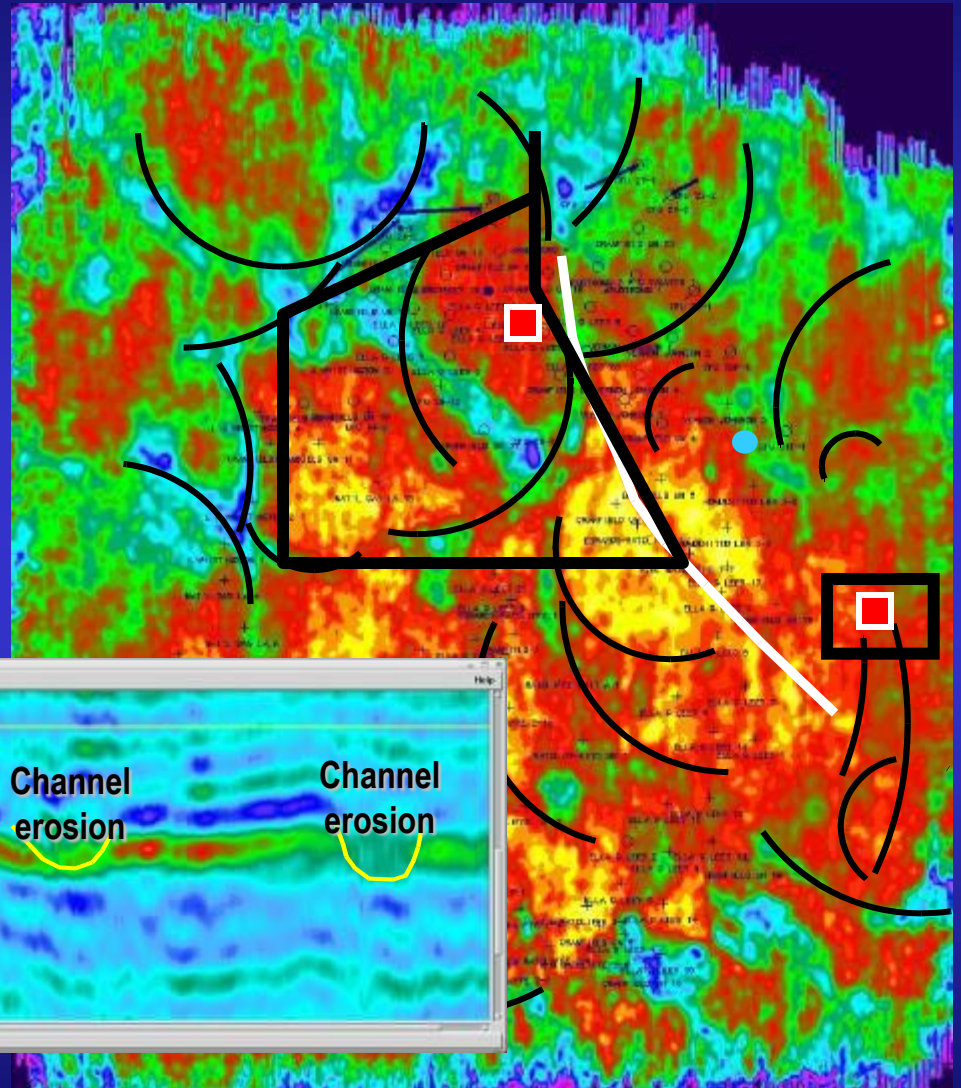
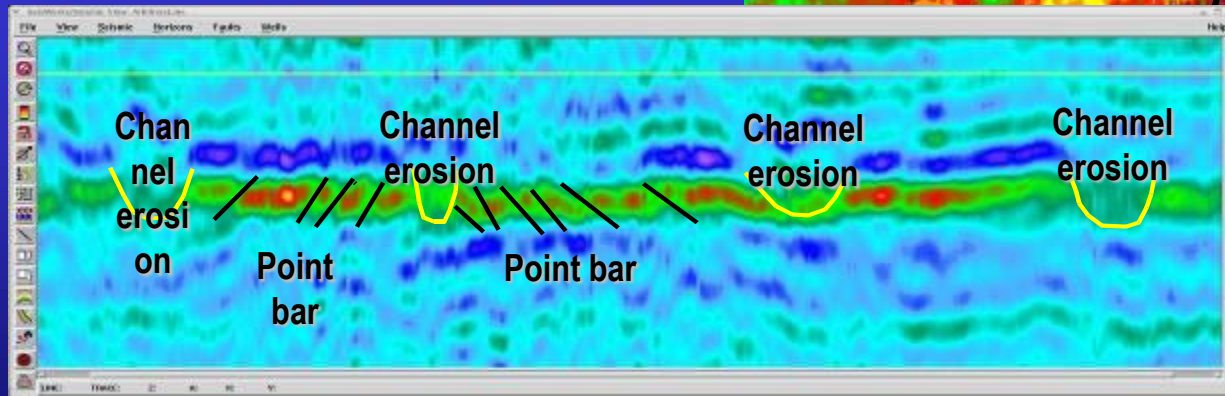
A

B



# Reservoir heterogeneity from surface seismic

- Stratal slicing for facies
- 90-degree phase
- AVF for thickness/fluid
- AVO for fluid/OWC

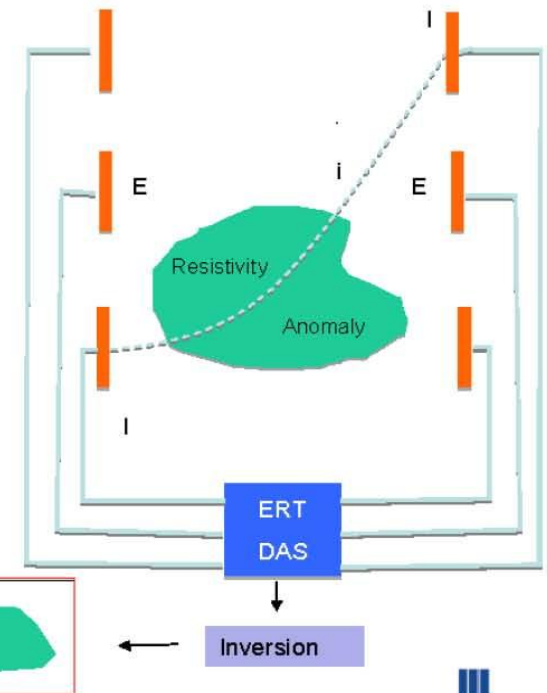
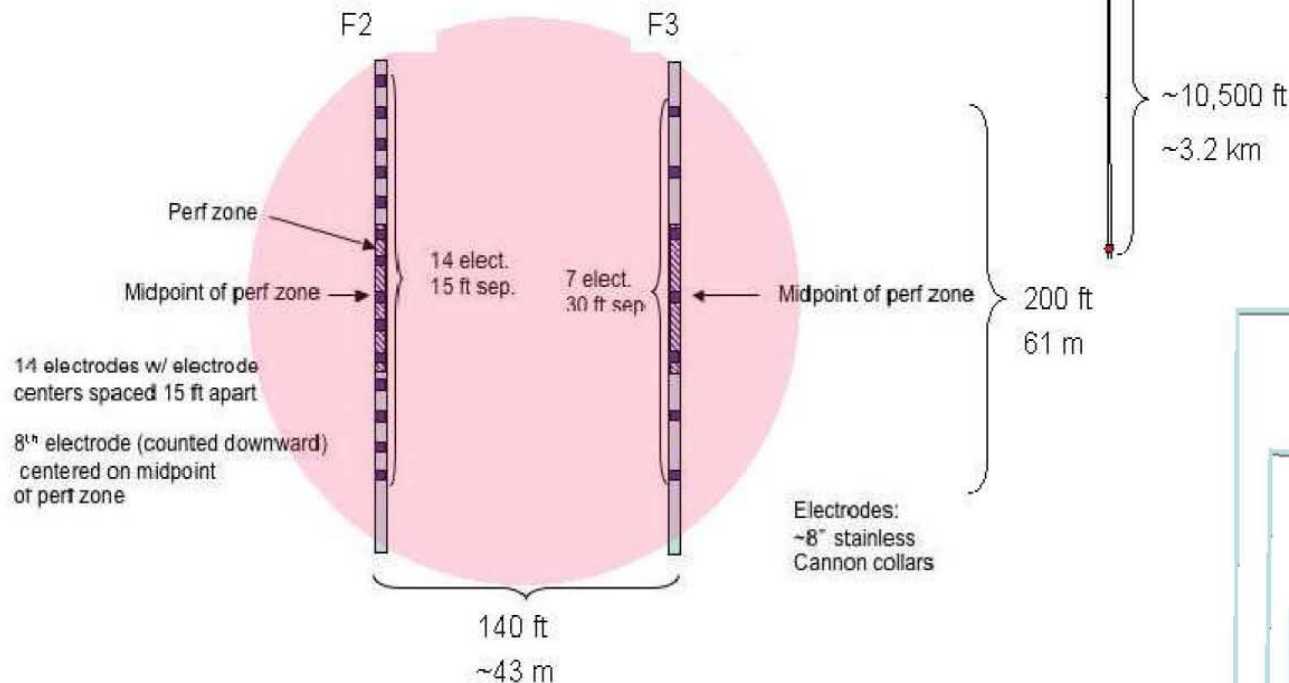


Denbury 3-D survey interpretation Hongliu Zeng, BEG



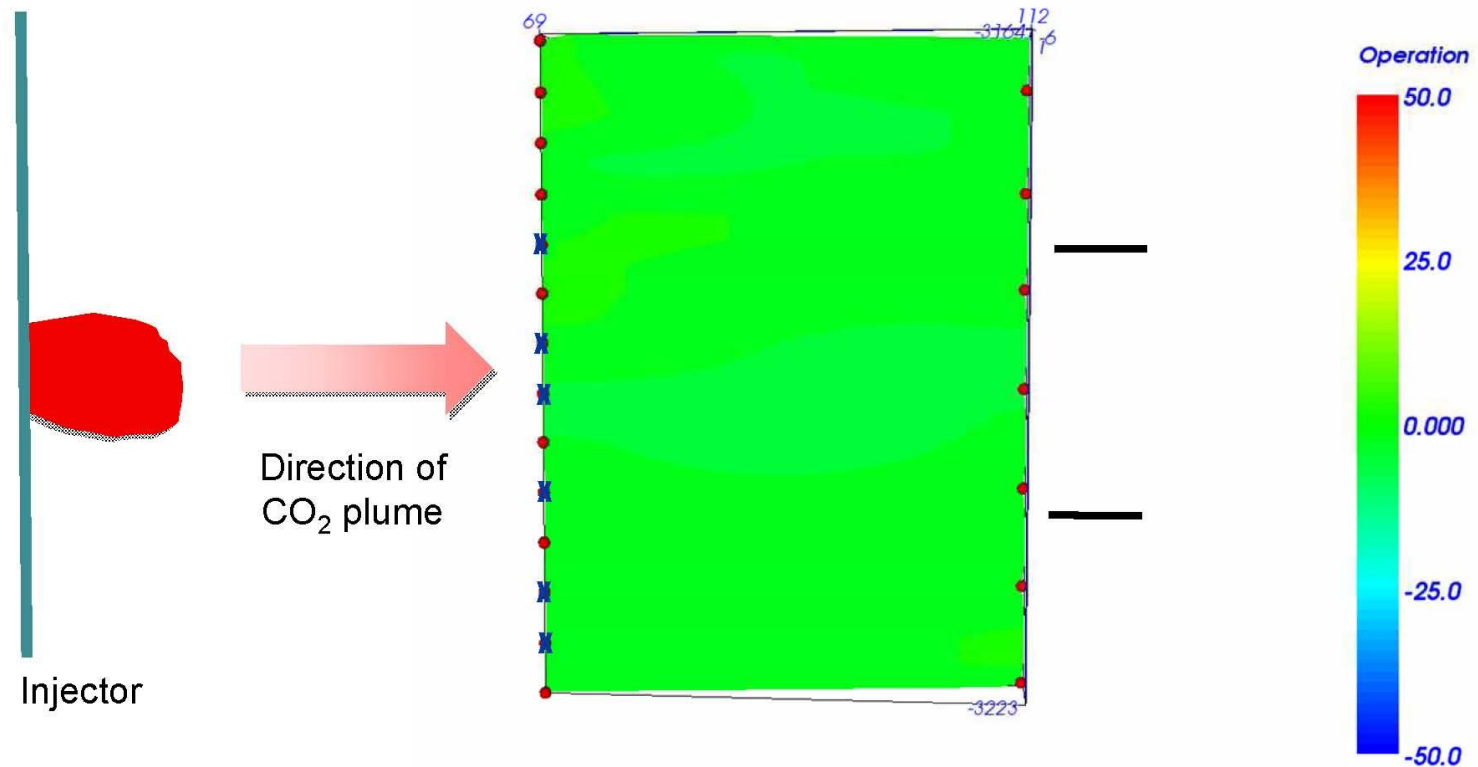
# Crosswell ERT (Electric Resistance Tomography)

Cranfield ERT Electrode Distribution



(Charles Carrigan et al., 2010)

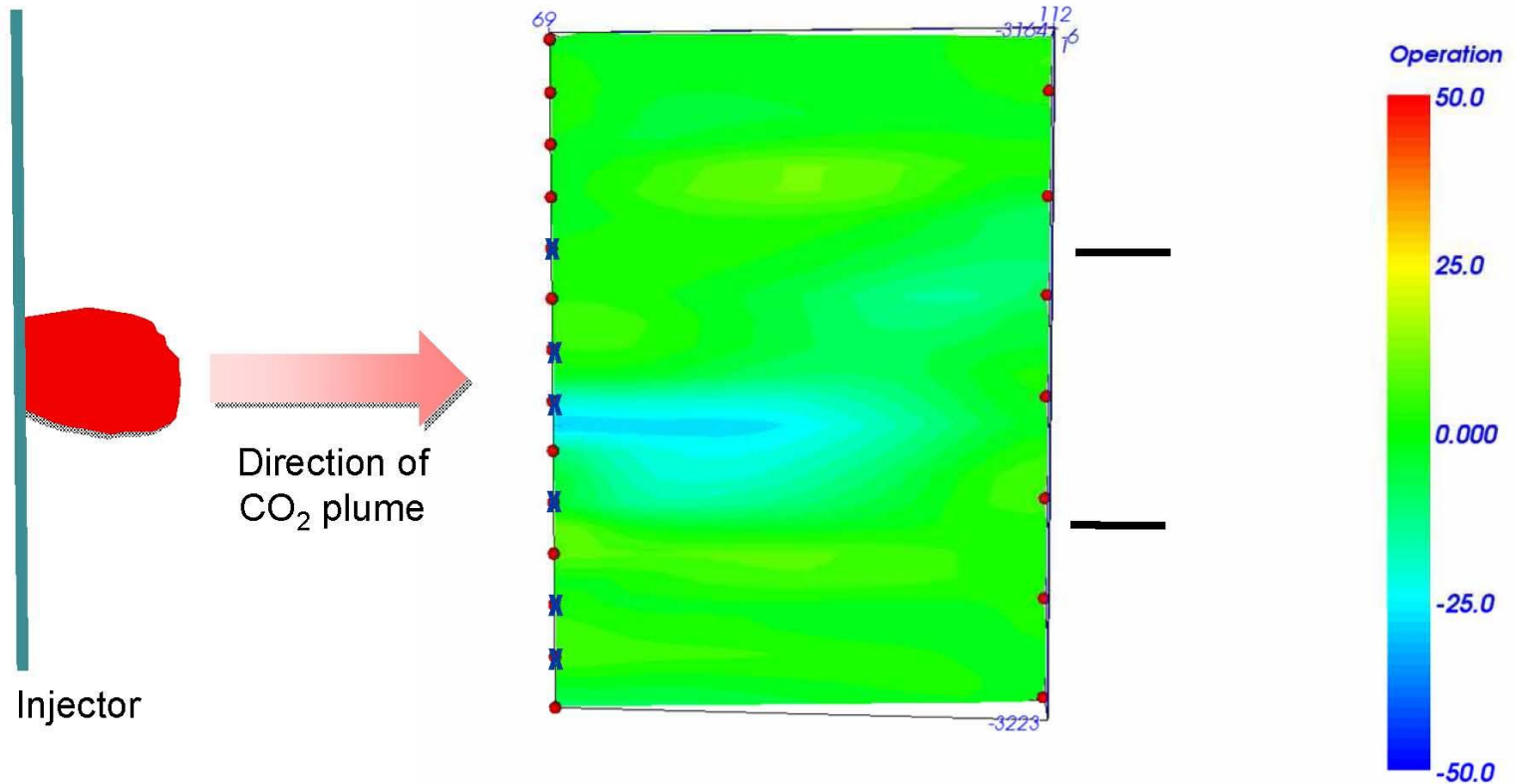
# Nullled Background at Initiation Of Injection (1 Dec 2009)



Multi-Phase Technologies, LLC

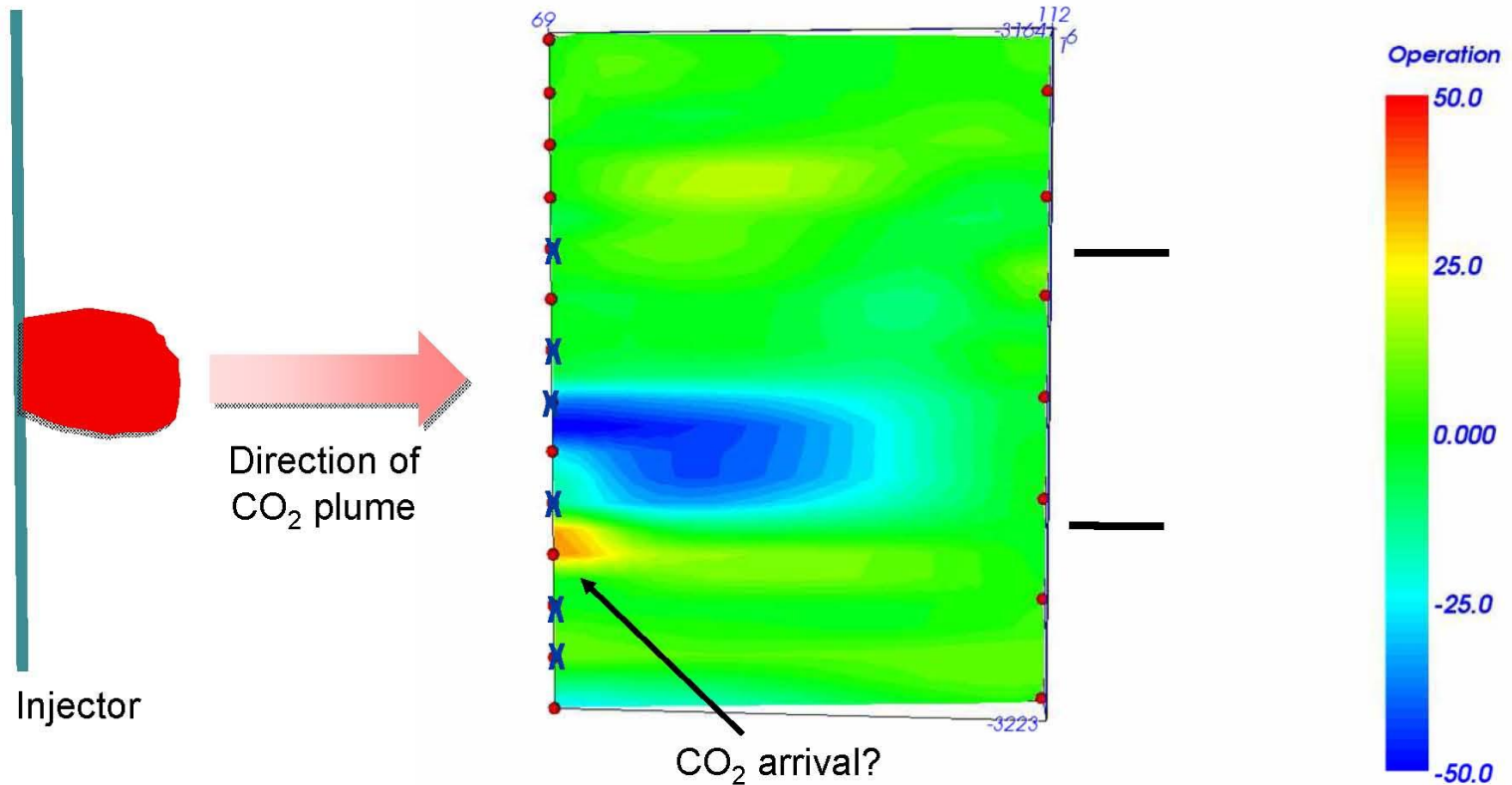
# Injector Workover Fluids?

(4 Dec 2009)



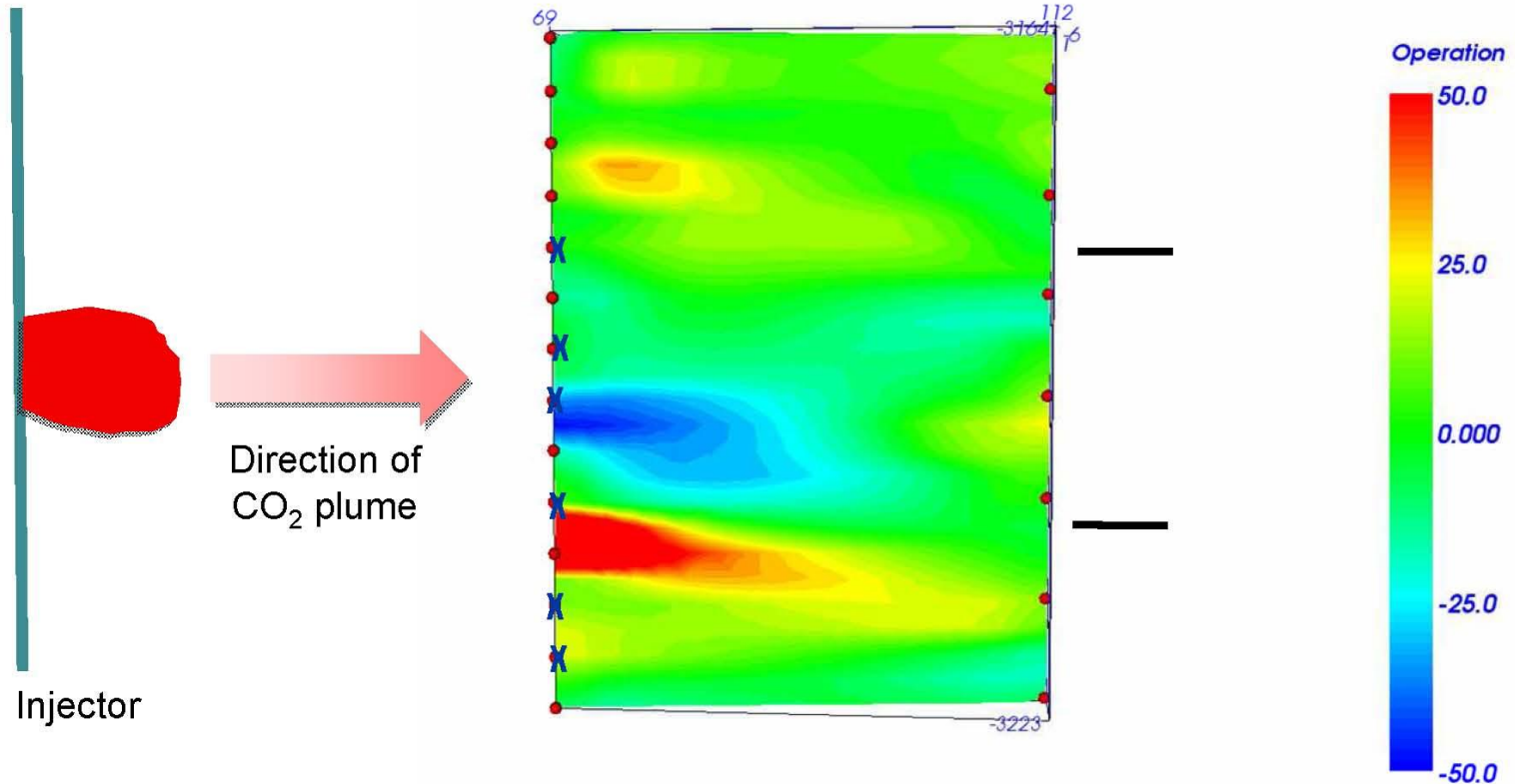
# Arrival of CO<sub>2</sub> Plume?

(9 Dec 2009)

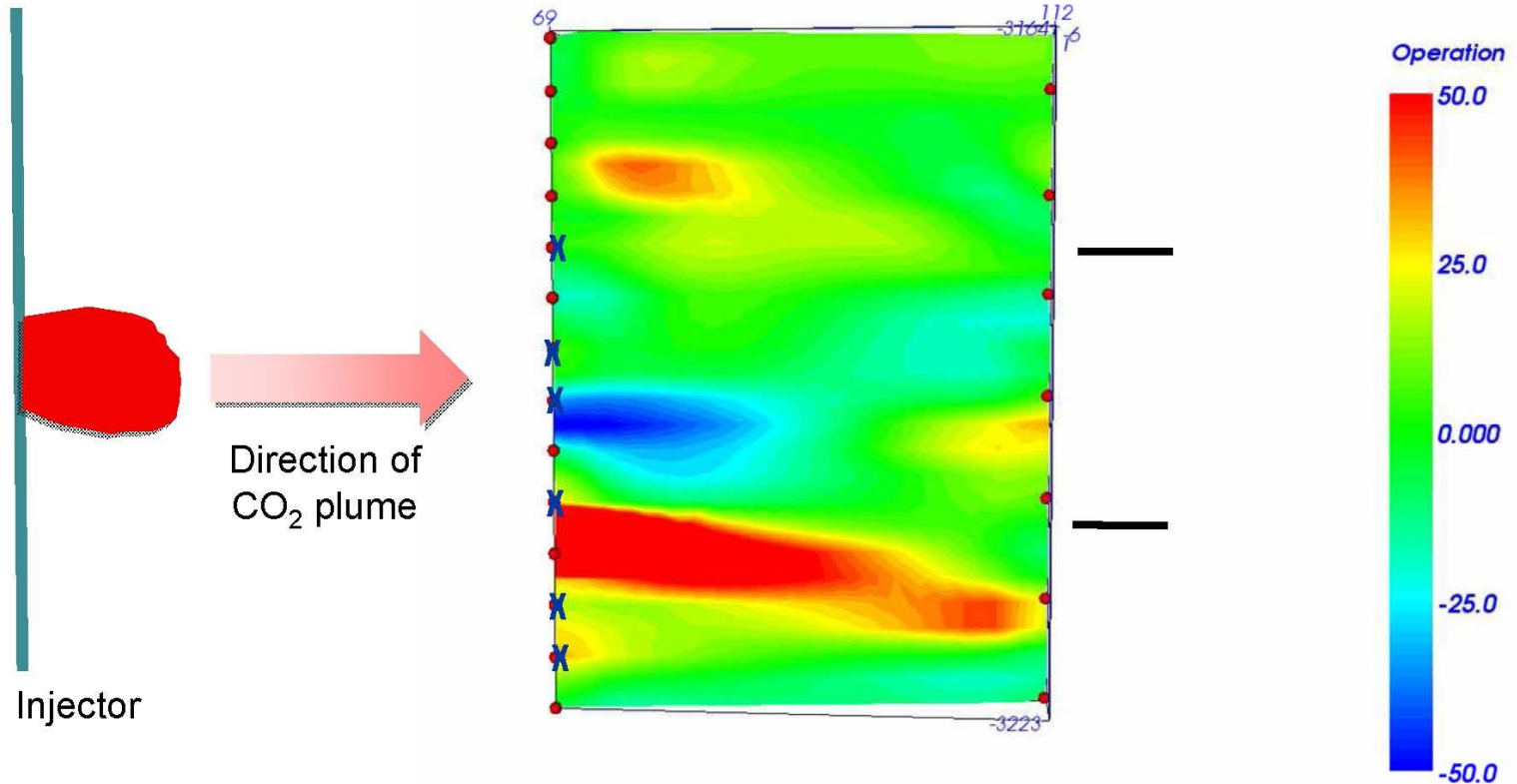




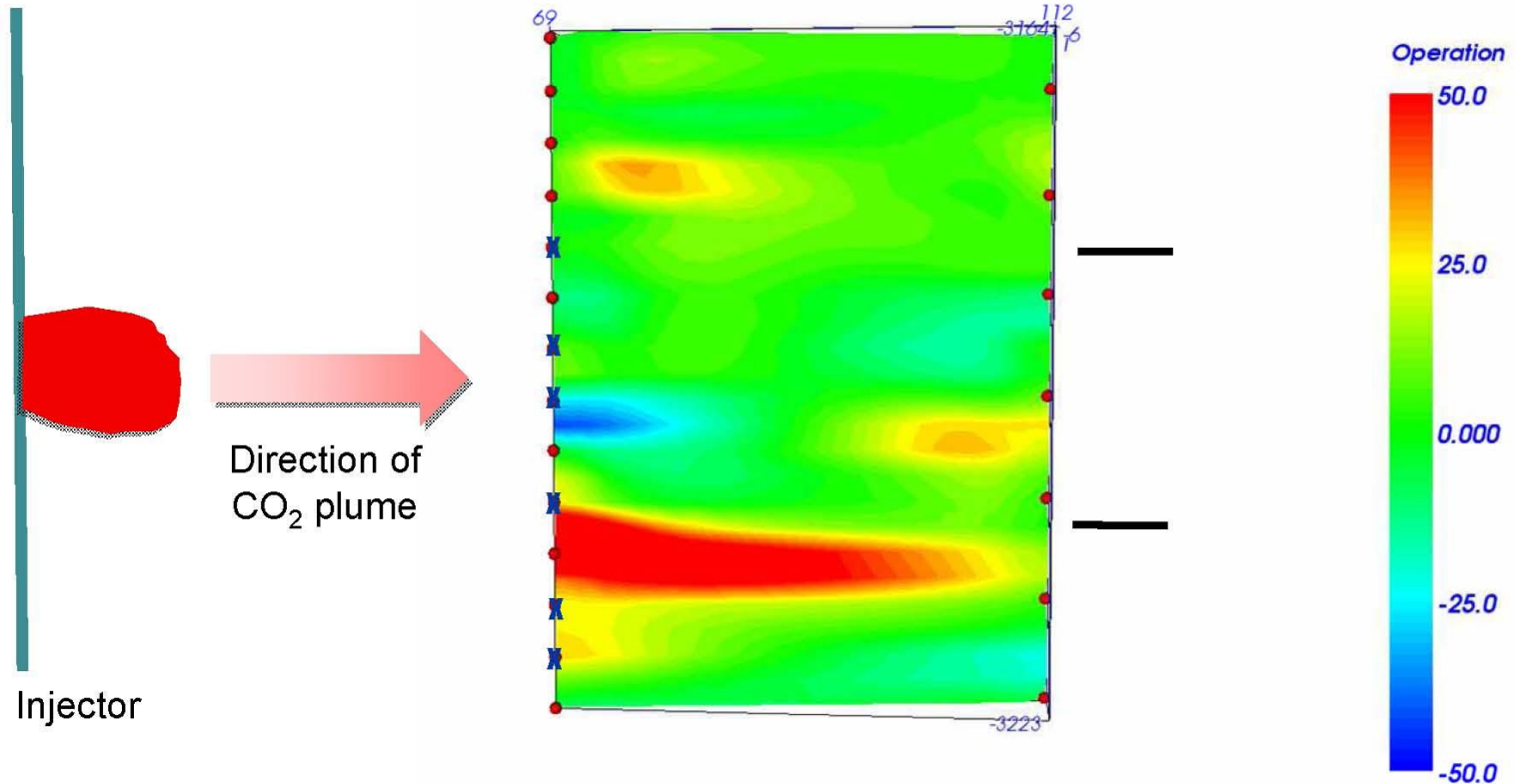
# Growth Of CO<sub>2</sub> Plume? (21 Dec 2009)



# Growth Of CO<sub>2</sub> Plume? (11 Jan 2010)

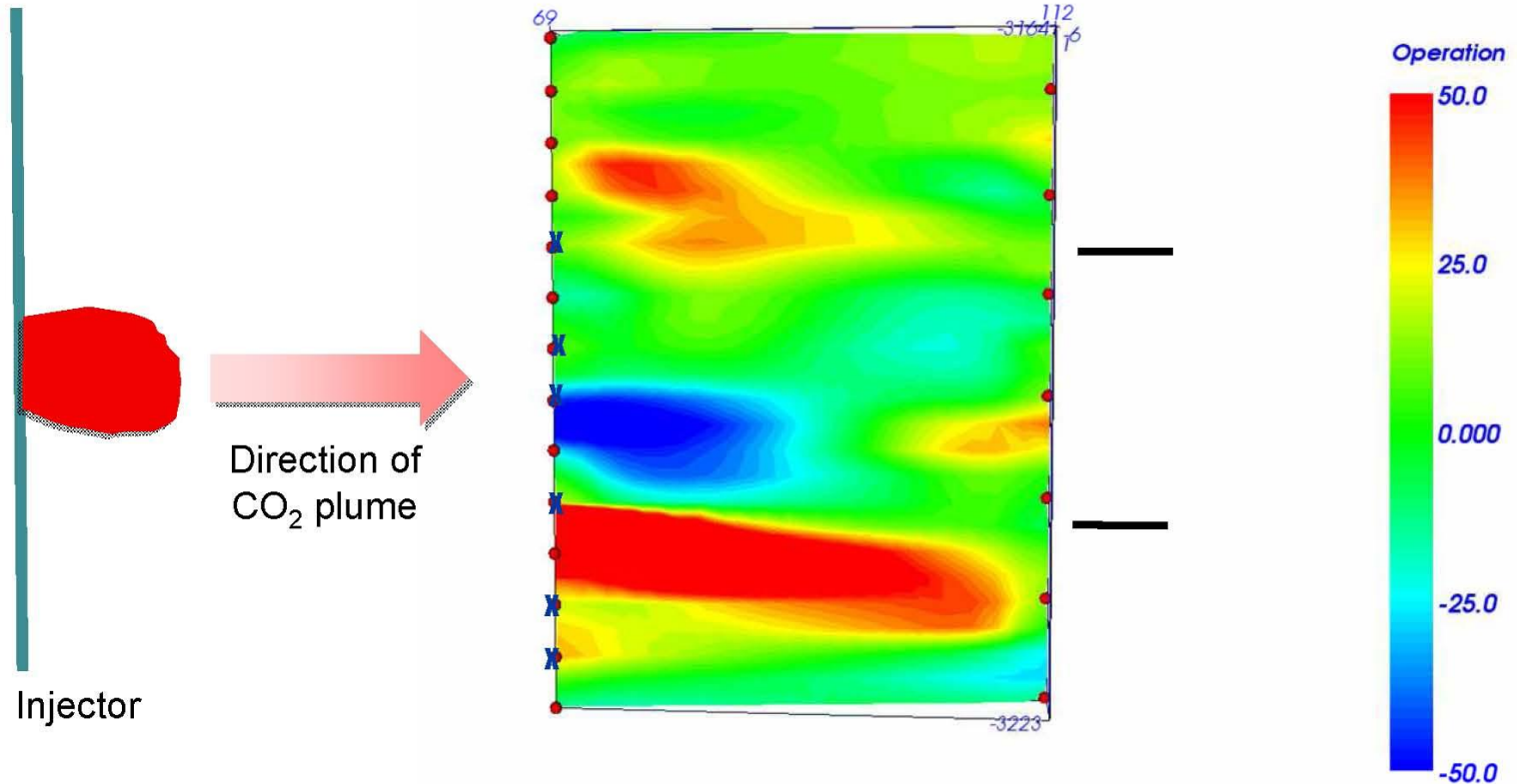


# Growth Of CO<sub>2</sub> Plume? (13 Jan 2010)



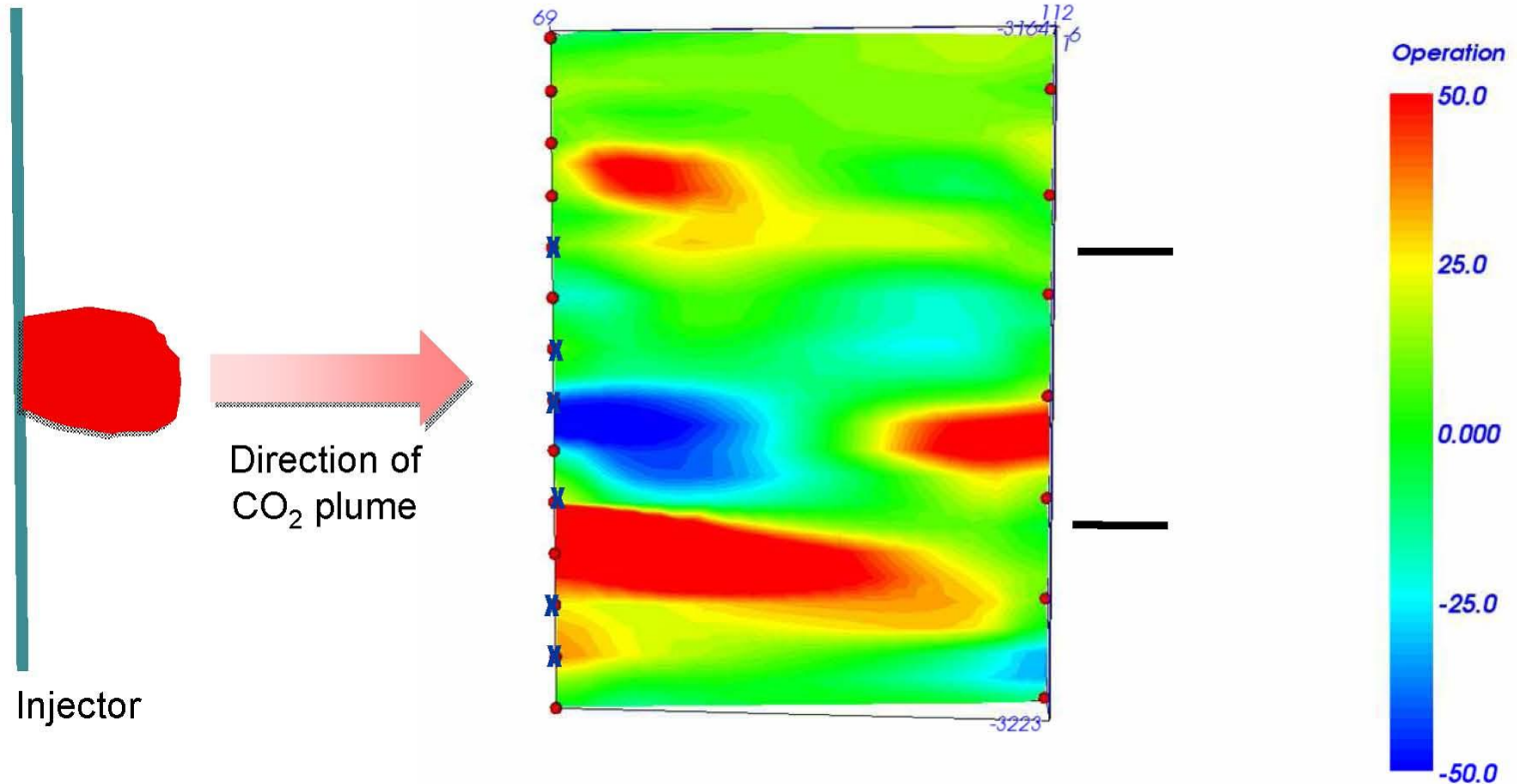
# Growth Of CO<sub>2</sub> Plume?

(5 Feb 2010)

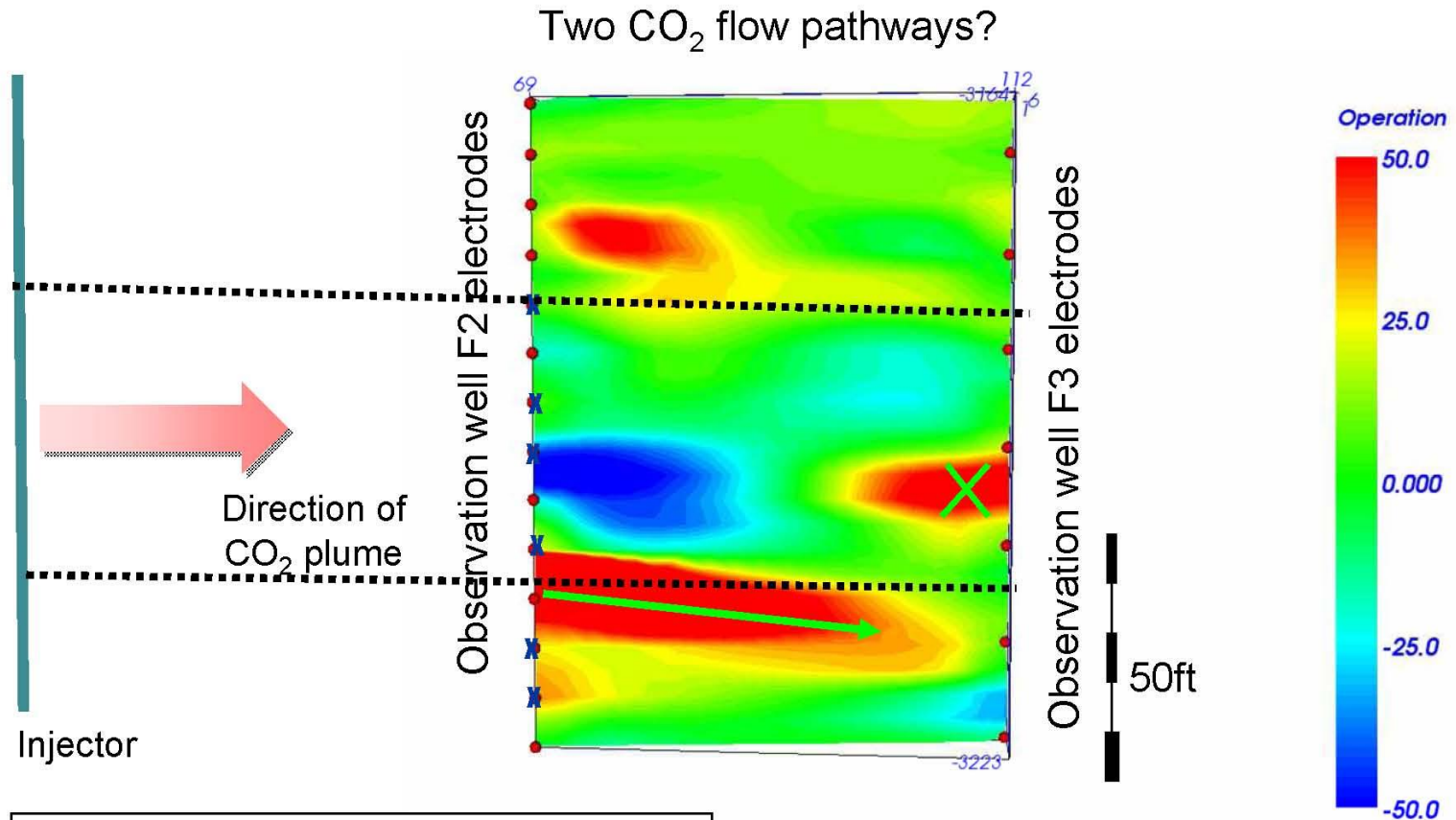




# Growth Of CO<sub>2</sub> Plume? (23 Feb 2010)



# Cross Well ERT – clues to how flow occurred

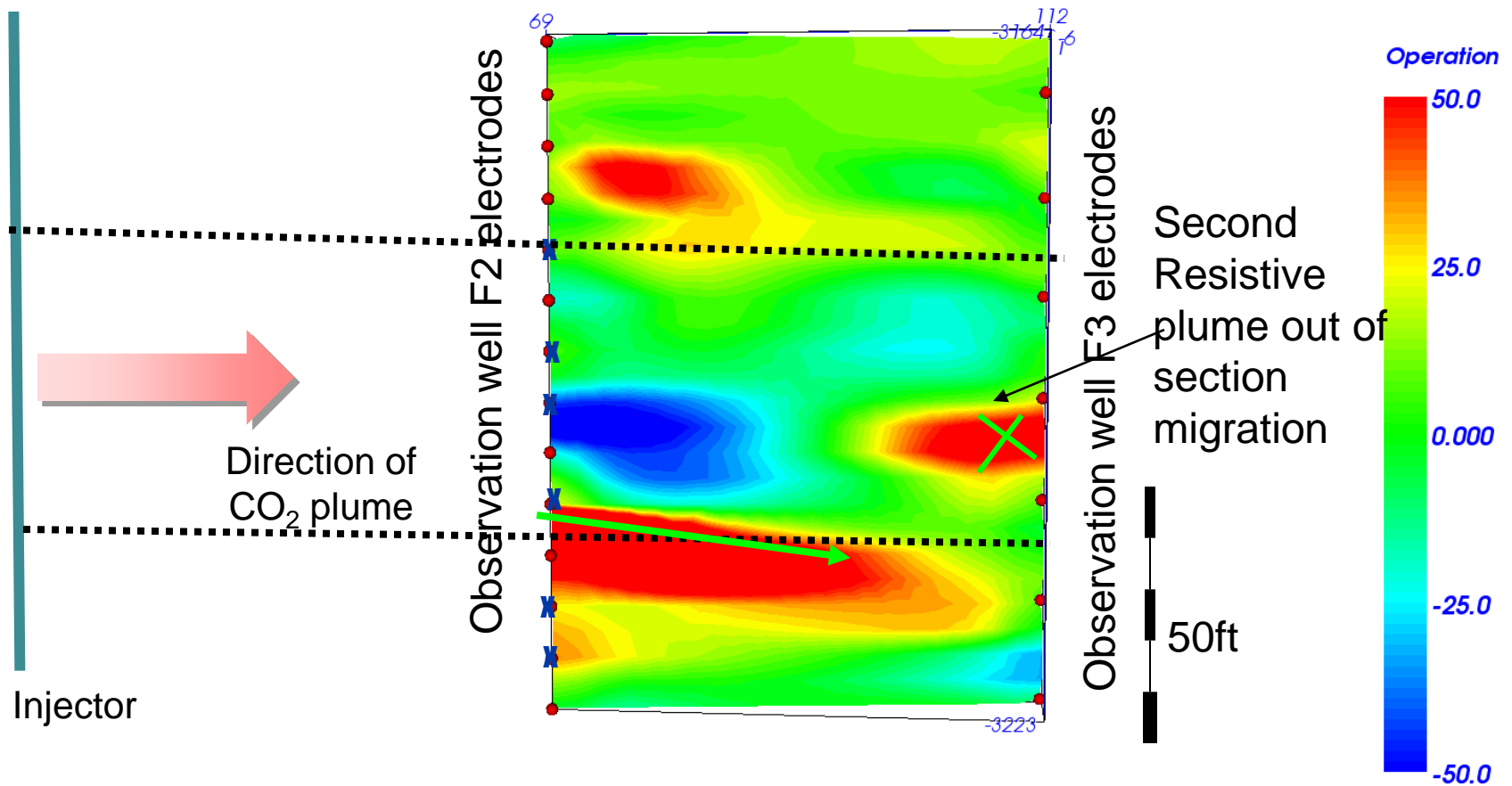


Resistive plume = CO<sub>2</sub> in reservoir  
Conductive plume = workover fluids?



Charles Carrigan, LLNL

# Cross Well ERT tells us how flow occurred

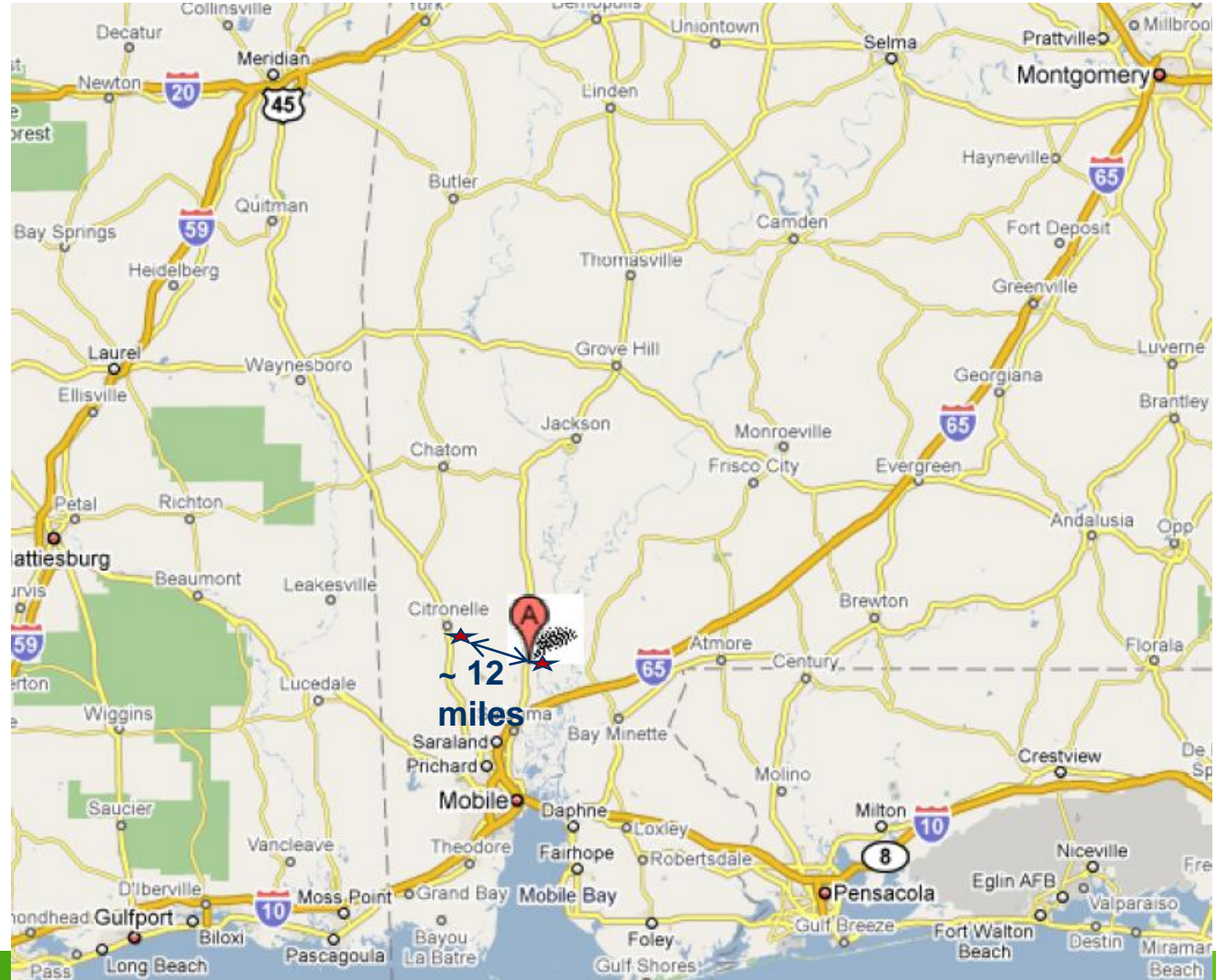


Resistive plume = CO<sub>2</sub> in reservoir  
Conductive plume = workover fluids?

# Phase III Anthropogenic Test

## Integrating Capture, Transportation and Storage of CO<sub>2</sub>

- CO<sub>2</sub> Capture Unit at Alabama Power's Plant Barry
- 12-mile CO<sub>2</sub> pipeline constructed by Denbury Resources
- CO<sub>2</sub> Injection at Denbury's Citronelle Field 2011-2013
- SECARB researchers will monitor injection and 3-years post injection

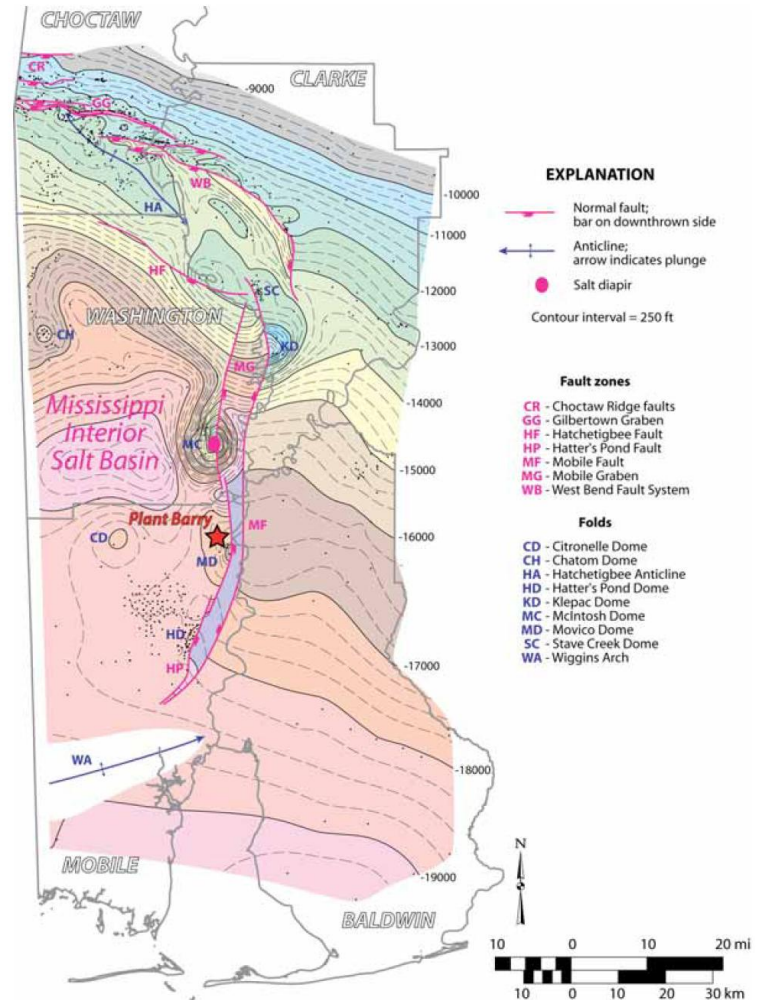




# Geologic Overview for Plant Barry and Citronelle Field

Proposed sequestration site is on the southeast flank of the Citronelle Dome

- Proven four-way closure
- No evidence of faulting or fracturing
- Multiple confining units between potential injection targets and base of USDW
- However, historic oil and gas wells and a lack of local characterization of saline reservoirs presents challenges

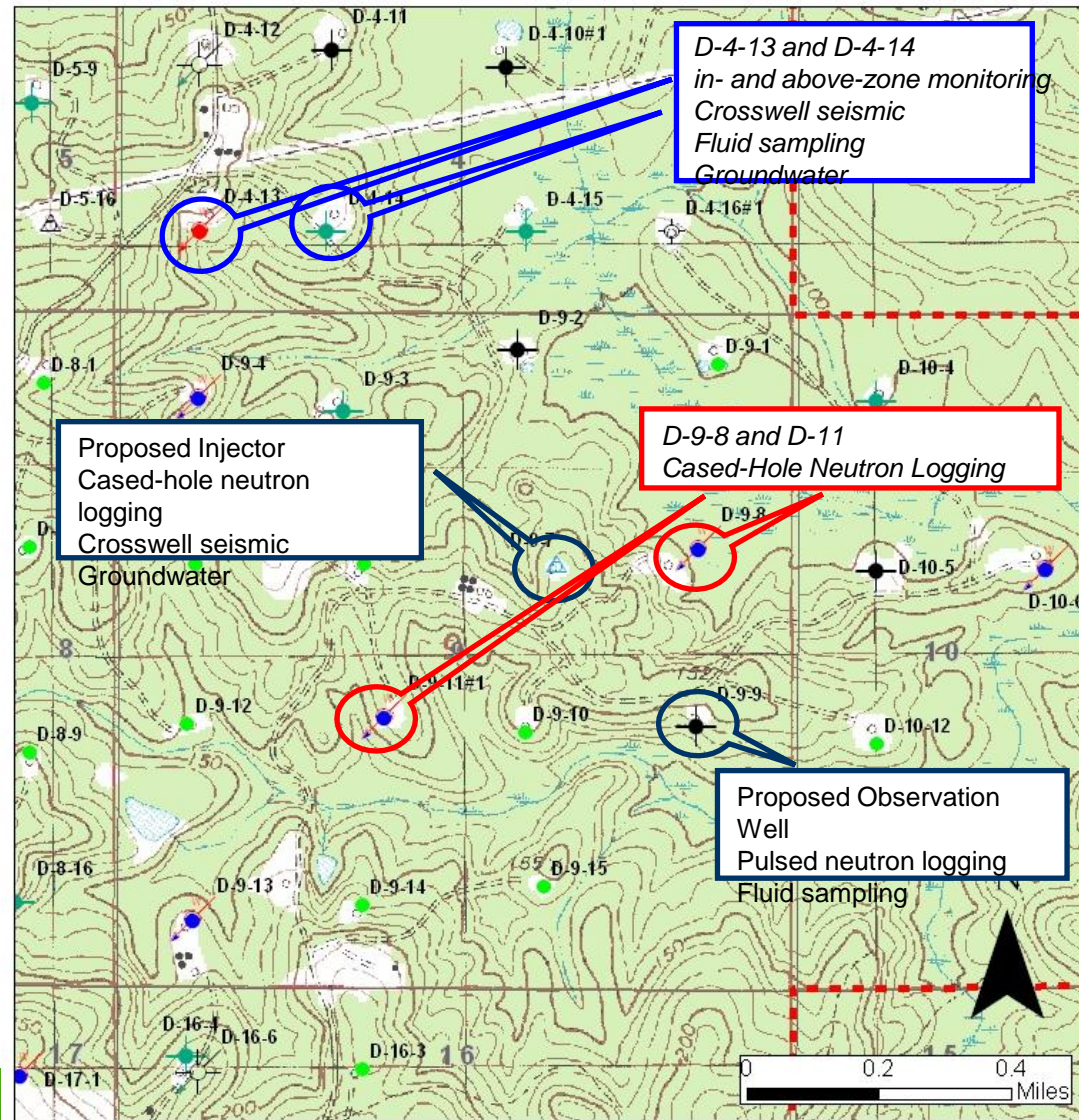


Structural contour map of the top of the Smackover Formation (Upper Jurassic) in southwest Alabama (GSA 2008)

# Expected Reservoir Intersection Depths at Citronelle

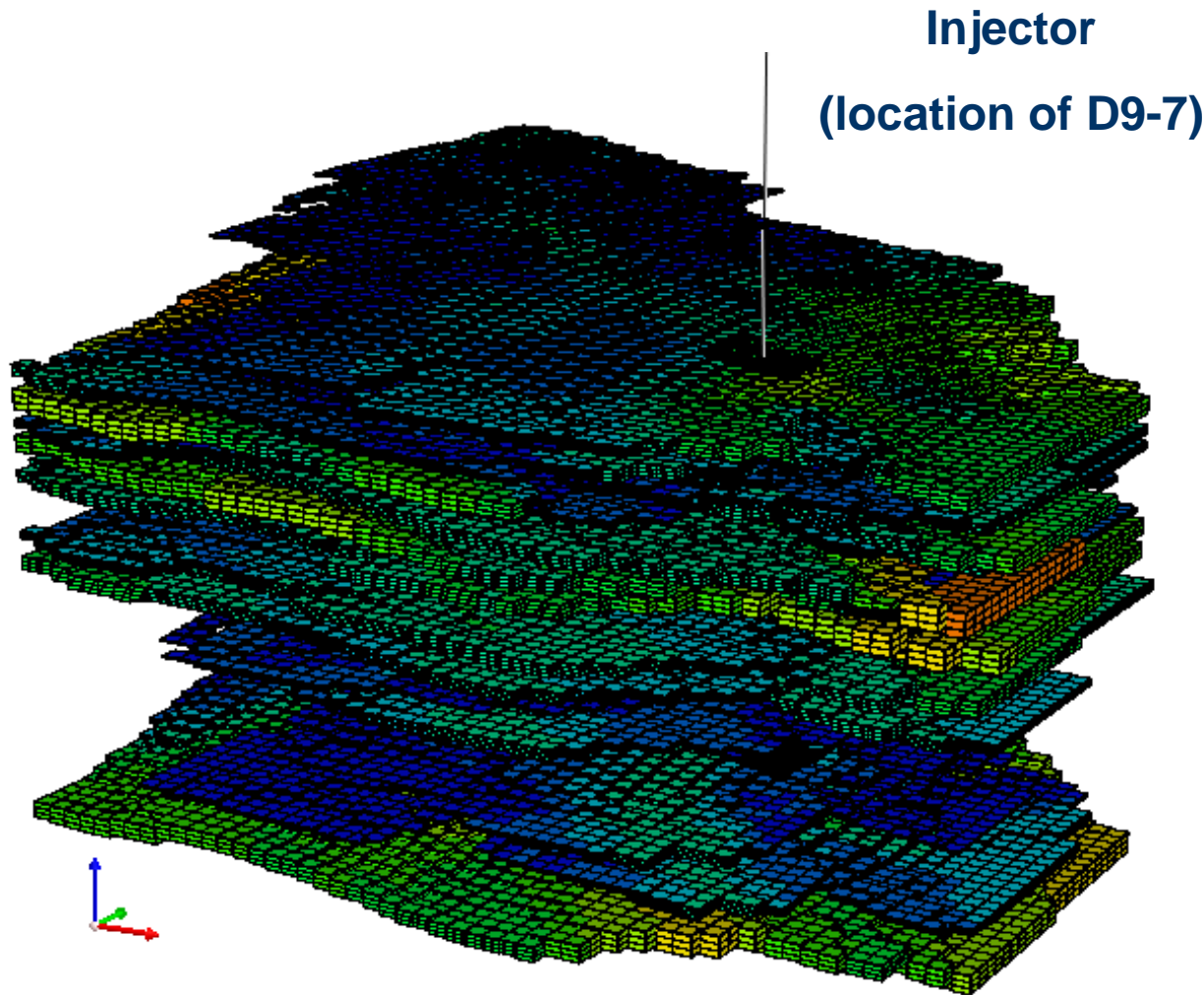
Formation Tops	Anticipated Depth Feet	Interval Thickness Feet
Bottom of Fresh Water (<1,000 mg/l)	~ 1,000	1,000
Bottom of Potable Water (<10,000 mg/l)	Max ~ 2,000	1,000
Selma Chalk Group	4,550	1,150
Eutaw Group	5,700	300
Upper Tuscaloosa Formation	6,000	700
Marine Tuscaloosa Formation	6,700	250
Lower Tuscaloosa Formation	6,950	300
Washita-Fredericksburg Undifferentiated	7,250	2,150
<b>Paluxy Formation</b>	<b>9,400</b>	<b>1,100</b>
Mooringsport Formation	10,500	250
Ferry Lake Anhydrite	10,750	200
Rodessa Formation (oil reservoir)	10,950	-

# CO<sub>2</sub> Injection Monitoring Plan





# Model 3-D View of Citronelle Injection Site

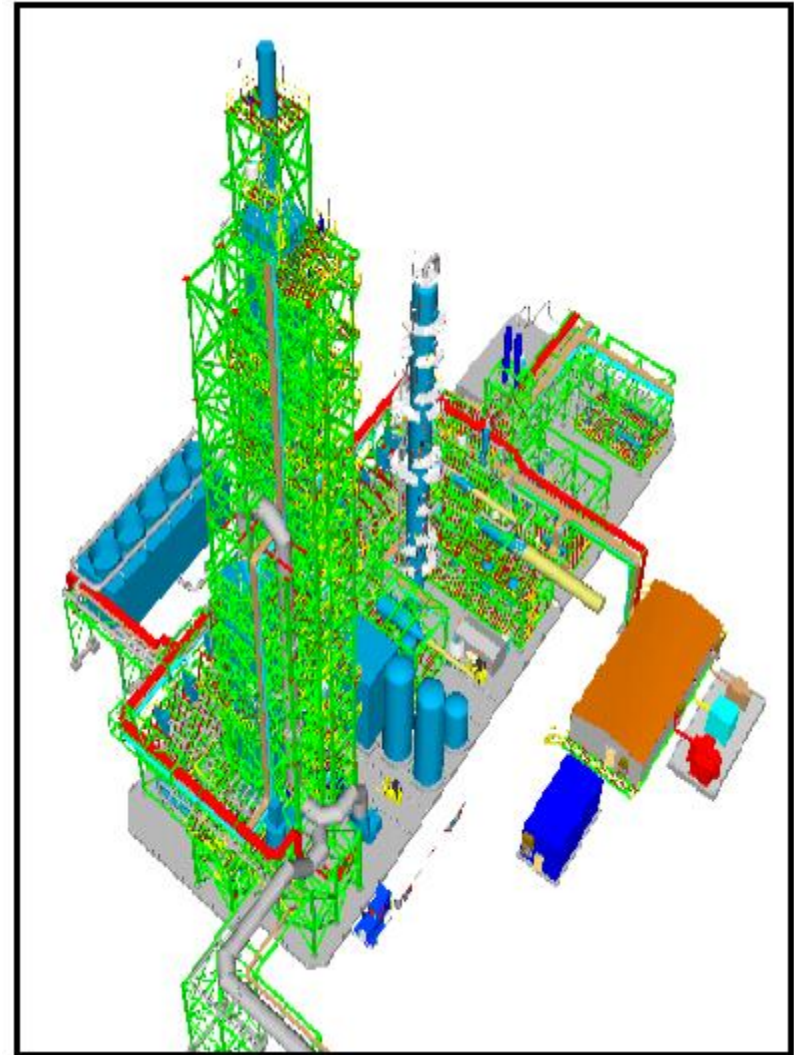


- 17 sand bodies from geological model
- Average permeability of 88 mD
- Average porosity of 19.3%
- Identical permeability and porosity in all layers

# Capture Unit at Alabama Power's Plant Barry

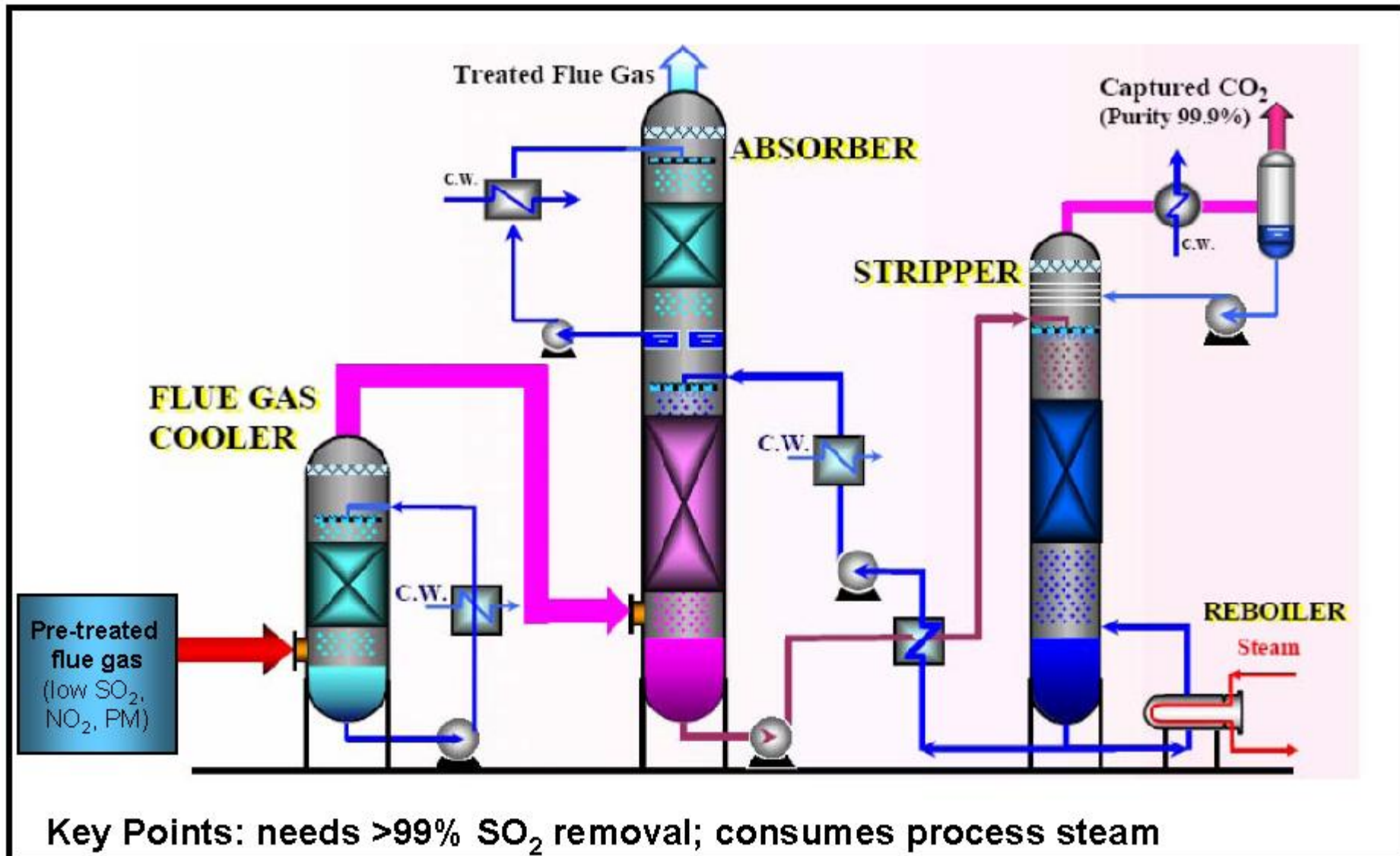
## MHI advanced amine capture unit

- 25 MW post combustion slip stream
- Fabricate off-site and barge to Plant Barry
- Compress CO<sub>2</sub> to 2000 psi
- Scheduled start up during summer, 2011
- Separately funded





# Simplified CO<sub>2</sub> Scrubbing Process (Amine)



# Groundbreaking Ceremony: Capture Unit

Alabama Power's Plant Barry, April 14, 2010, Bucks, Alabama



**SOUTHERN  
COMPANY**

**mitsubishi**  
HEAVY INDUSTRIES, LTD.

**EPRI** | ELECTRIC POWER  
RESEARCH INSTITUTE



# Site Progress Photos (7-28-10)



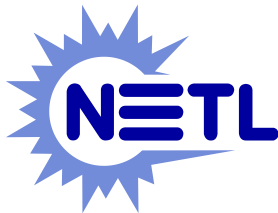


# Modular Transportation Photos (9-23-10)



# Integration Questions

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- What business relationships must be established among the CO<sub>2</sub> provider, transporter and injection field operator?
- How can a CO<sub>2</sub> transportation and injection system impact plant operations and scheduling?
- How can cycling a plant on-line and off-line impact CO<sub>2</sub> transportation and injection?
- What types of communications and control systems are needed to support integration?
- How can lessons learned assist in scale up?





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